Beam Instrumentation Development of an Abort Gap Monitor for the LHC

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What is the Abort Gap and Reasons for Monitoring It

• 3.3 μs gap in the machine fill, corresponding to the raise time of the abort kicker.

• Gap can populate by:

- Injection errors (450 GeV, fast mechanism)
- Diffusion (mainly 7 TeV, slow mechanism)
- Debunching (mainly 7 TeV, slow mechanism)

This may cause:

• Quenching of SC magnets (Q4 after septum in IP6)

also:

• *"Radiation flashes" during ramp (unbunched beam)*

LHC Specifications

(C. Fischer, LHC-B-ES-0005)

- Maximum allowable charge density:

  $6 \cdot 10^{6}$ p/100 ns @ 7 TeV

  $4 \cdot 10^{9}$ p/100 ns @ 450 GeV

- Integration time:

  100 ms (~1100 turns)

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the **Large Hadron Collider** project

LHC Project Document No. **LHC-B-ES-0005.00 rev 2.0**
CERN Div./Group or Supplier/Contractor Document No. **AB/BDI**
EDMS Document No. **328145**

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Functional Specification

HIGH SENSITIVITY MEASUREMENT OF THE LONGITUDINAL DISTRIBUTION OF THE LHC BEAMS

Abstract

The present specification provides the functional requirements of a monitor that will measure the longitudinal density distribution of the LHC beams with a wide dynamic range of more than 10^{5}. This monitor is particularly suited to measure the tails of the bunches, to detect ghost bunches or a debunched fraction of the beam. It can be used to monitor the dump gap and ensure it does not become filled with beam. Data related to the beam core distribution: centre of gravity, edges, length, shape, will also be measured.

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Techniques for the AGM

Synchrotron Radiation

- **Gated PMT**
- APDs

  recovery time, gating

- Streak camera

  recovery time, $$

Wake Fields

- BPM's
- Wall current monitor

resolution (10 nA)

impedance ?

MCP-PMT for the AGM

Gate min. raise time: 1 ns

<2.5 ns RF bucket spacing; can gate out filled buckets

<<100 ns resolution

Gate voltage: 10 V

Low voltage switching required

Max gain: 10^6

< 10 dark counts/sec

High S/N

Max duty cycle: 1%

Max gate length: 10 μs

HAMAMATSU

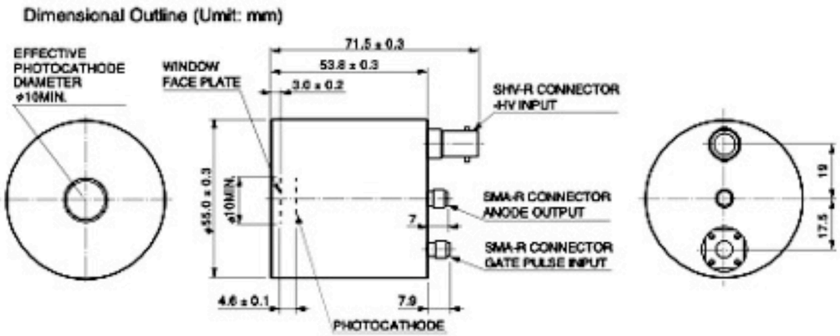
GATEABLE MICROCHANNEL PLATE PHOTOMULTIPLIER TUBE (MCP-PMTs)

R5916U-50 SERIES

Featuring Fast Gating Function with Improved Time Response and Switching Ratio

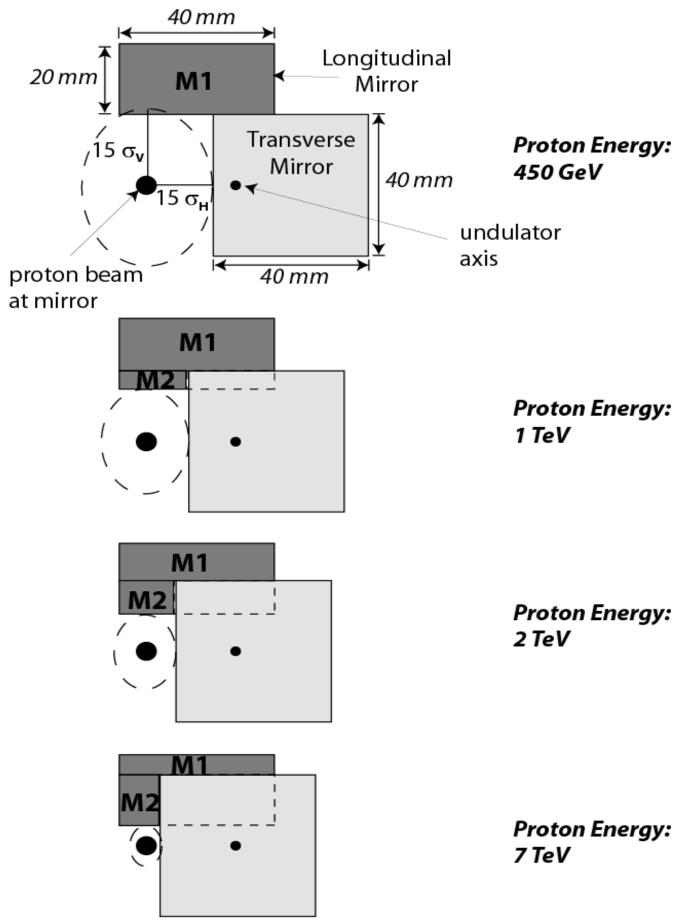
FEATURES
- High Speed Gating by Low Supply Voltage (+10V)
  - Gate Rise Time : 1 ns [1)]
  - Gate Width : 5 ns
- Fast Rise Time : 180 ps
  - Narrow TTS [2)] : 90 ps
- High Switching Ratio : 10^8 at 500 nm
- Low Switching Noise
- Low Dark Noise
- Variety of Photocathode Available

APPLICATIONS
- Environmental monitoring
- Satellite laser ranging
- Fluorescence decay analysis



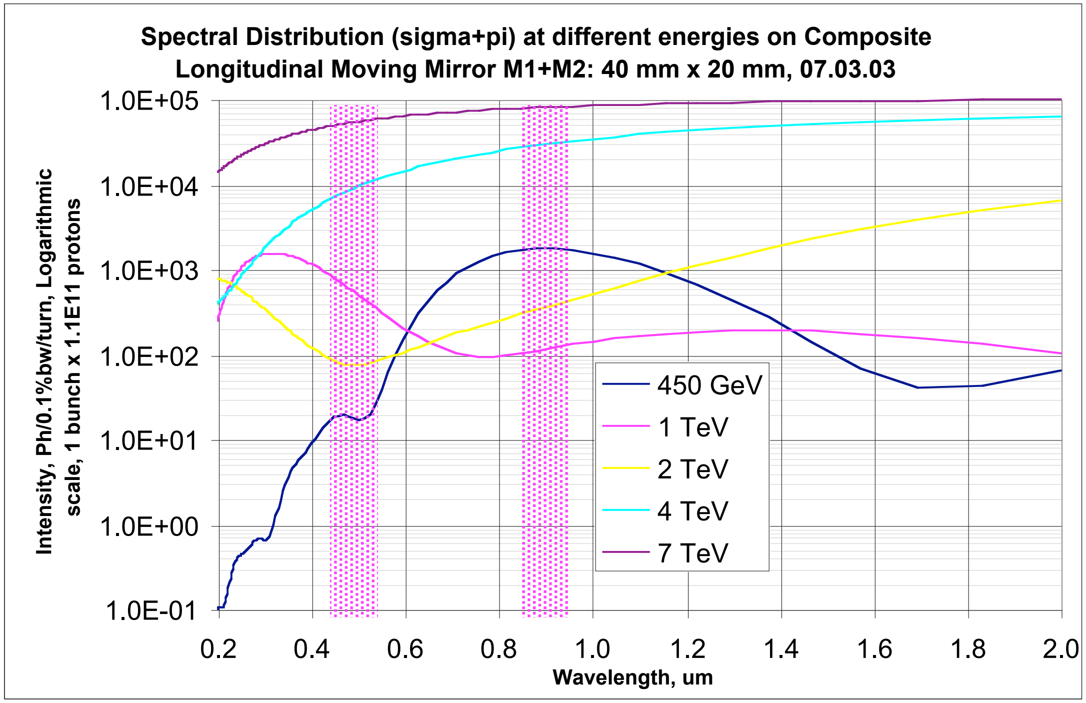
Synchrotron light source for longitudinal diagnostics

Extraction mirror



- 5T SC undulator in IR4 (low energy)
- Exit edge of D3 magnet (high energy)

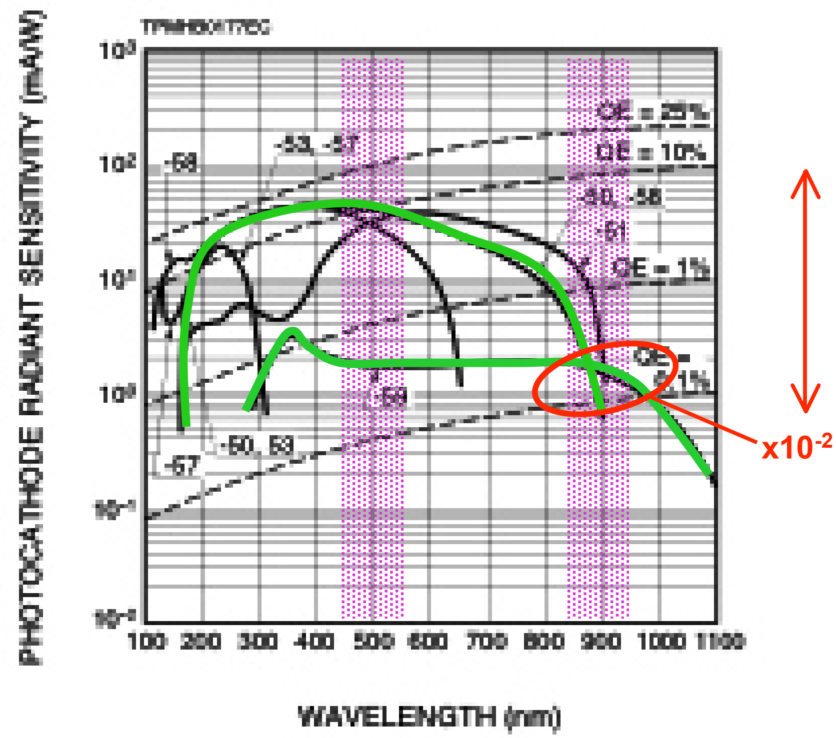
Available photon flux



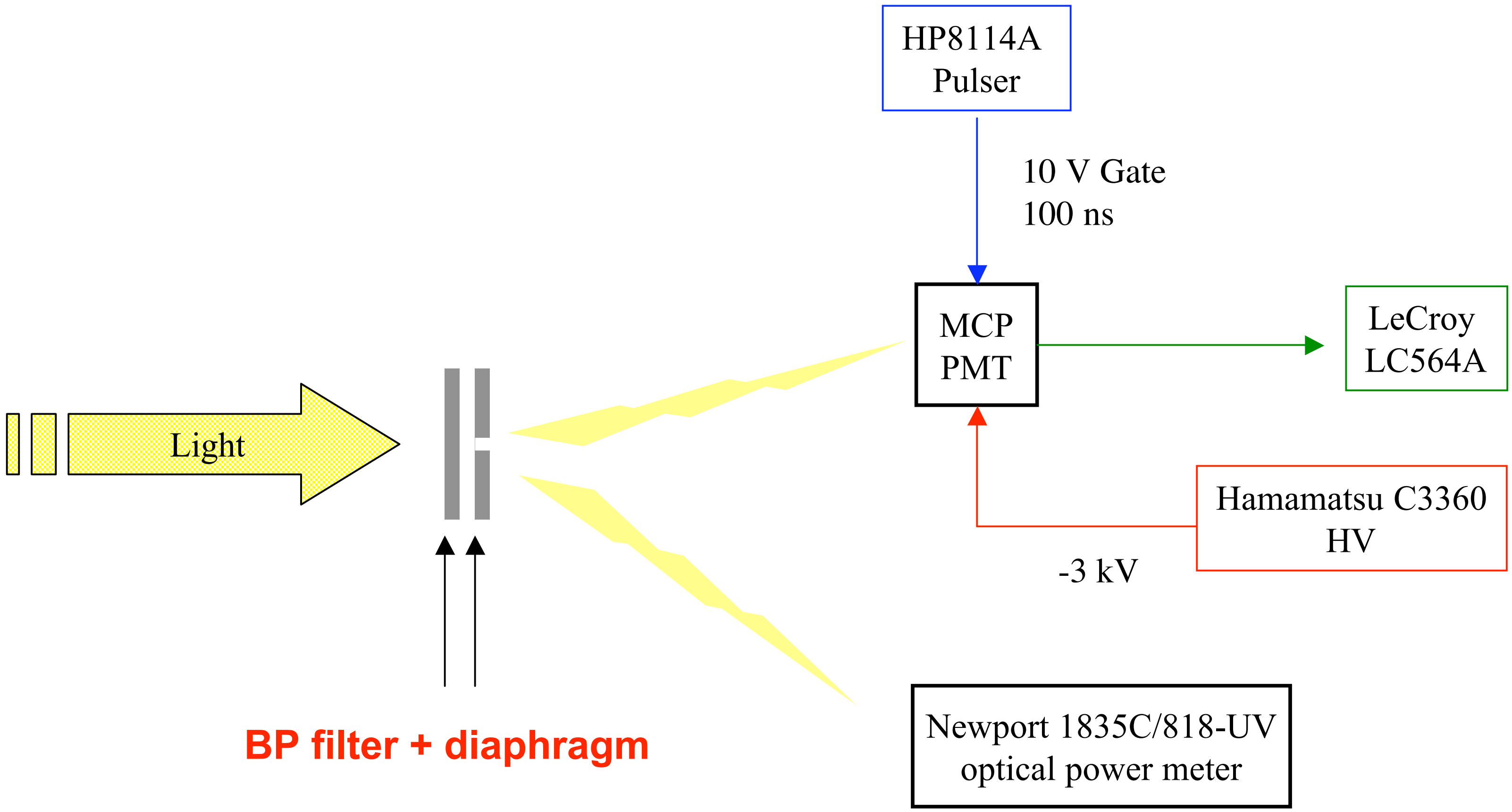
(M.Facchini)

MCP-PMT has the required sensitivity

Conservative estimates (1% QE, 10% BW, etc.) point out that a MCP-PMT based AGM can easily detect the required charge densities at both injection and collision energy.



Sensitivity Bench Tests

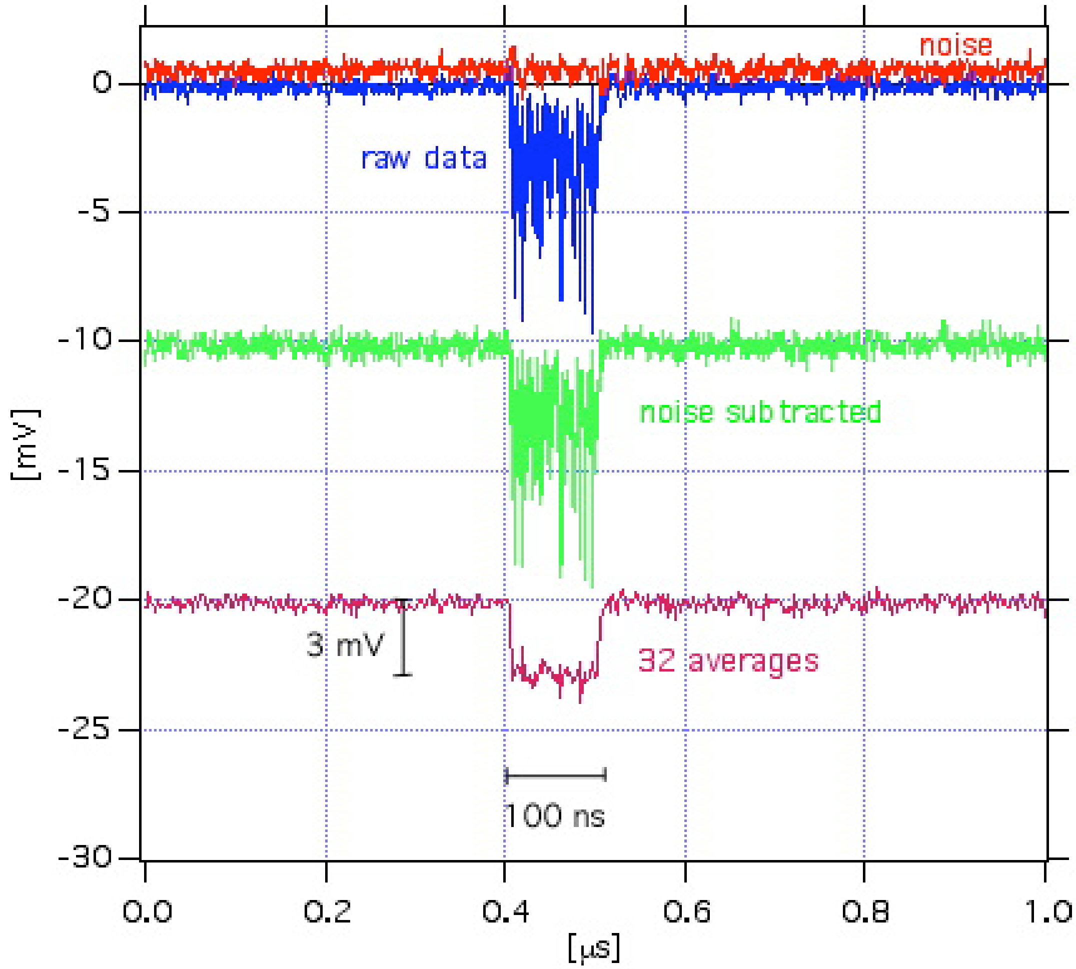


Light intensity is adjusted to simulate photon flux in the LHC

Sensitivity Bench Tests Results

Photon flux (140 ph/turn) equal to what expected in the LHC at 7 TeV with a 5% bandwidth at 500 nm.

Flux at 450 GeV is 4 to 5 times lower.
However: MCP-PMT gain can still be increased and bandwidth would be larger.



AGM Beam Tests

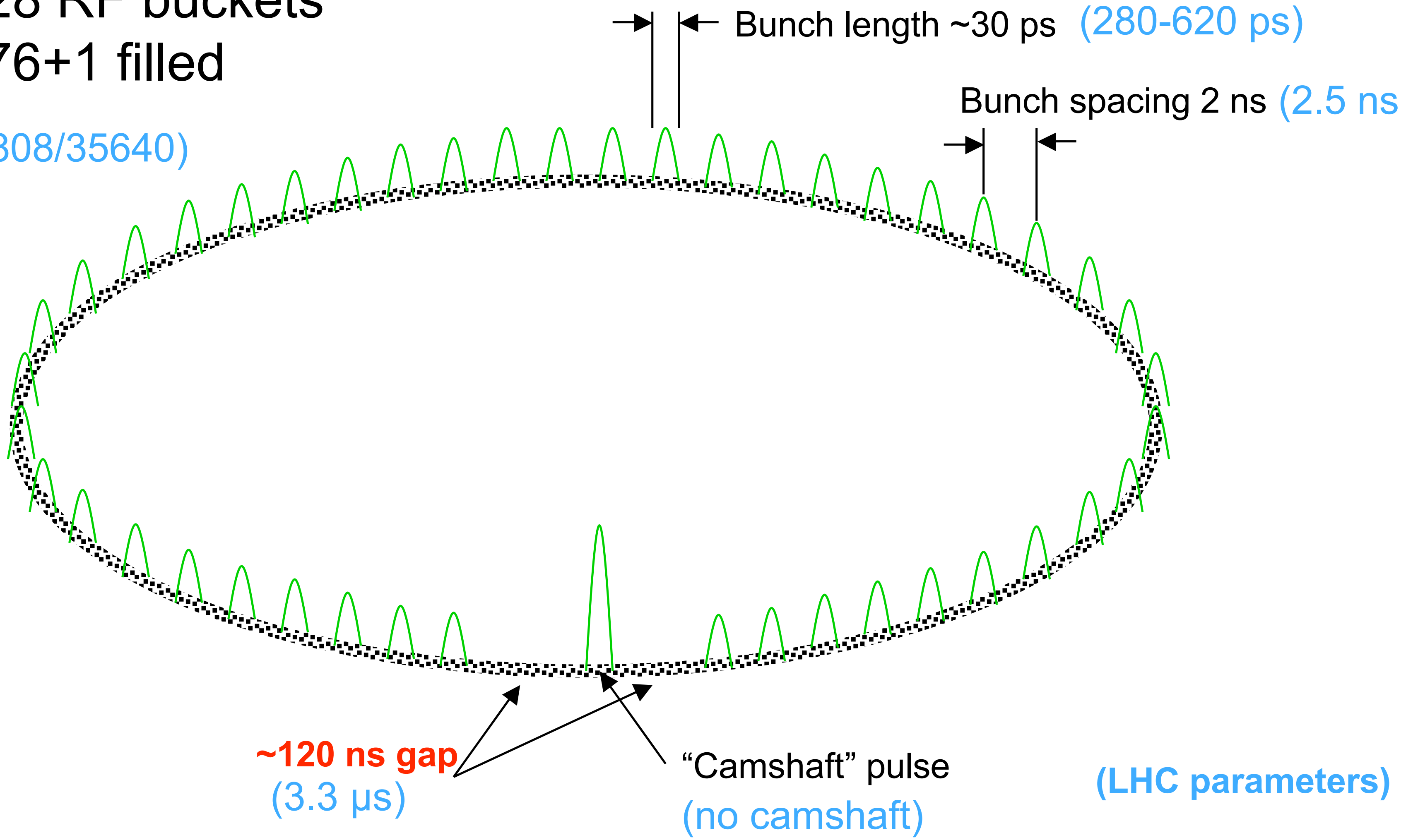
- An MCP-PMT has been tested at the ALS (*dynamic range*, *photocatode saturation*, *noise properties*) and on the Tevatron (*unbunched beam*).

- The MCP-PMT will also be tested as a possible device for accelerator physics applications (bunch length, tails, etc.).

Tests at the ALS

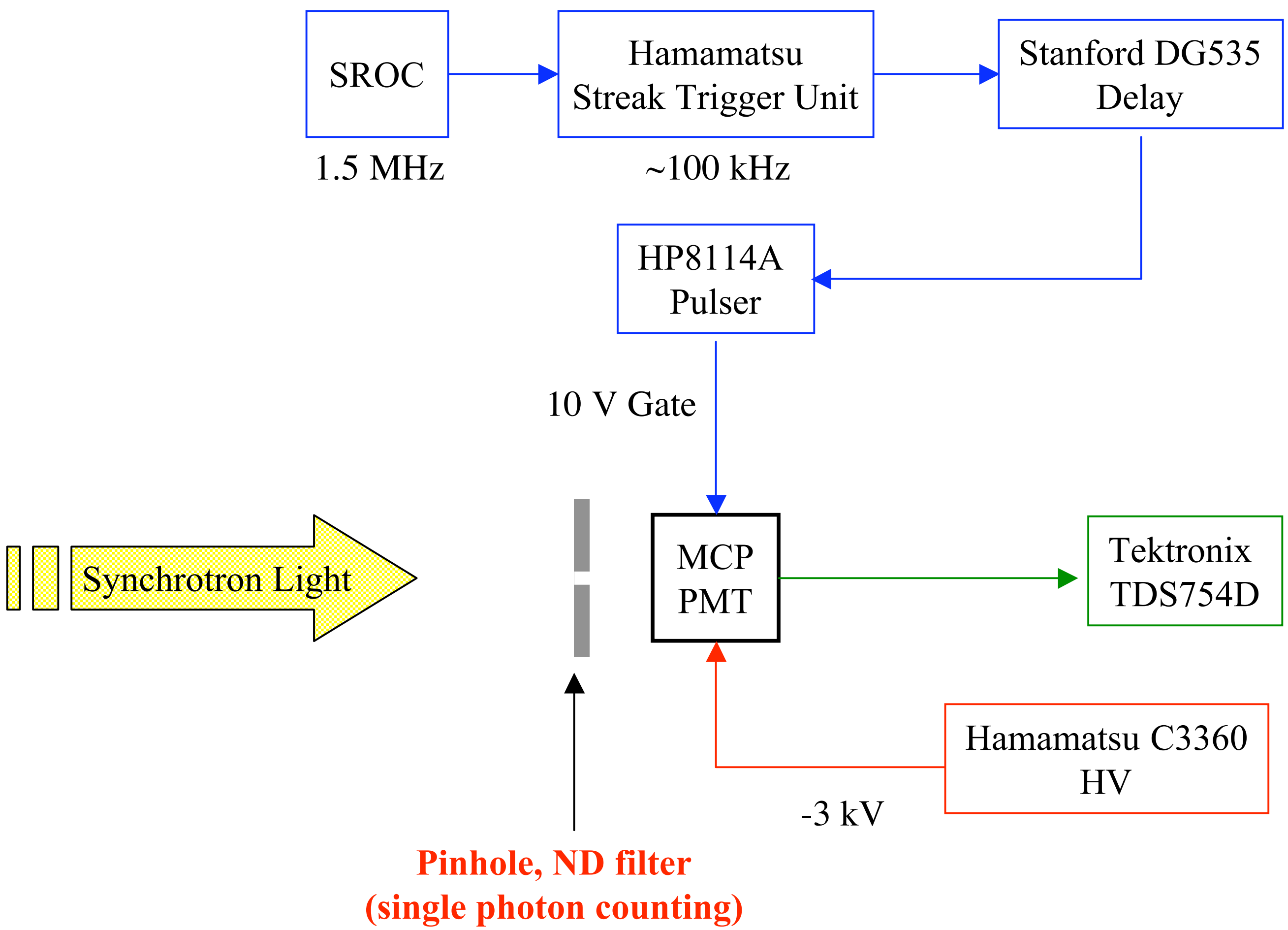
328 RF buckets
276+1 filled

(2808/35640)

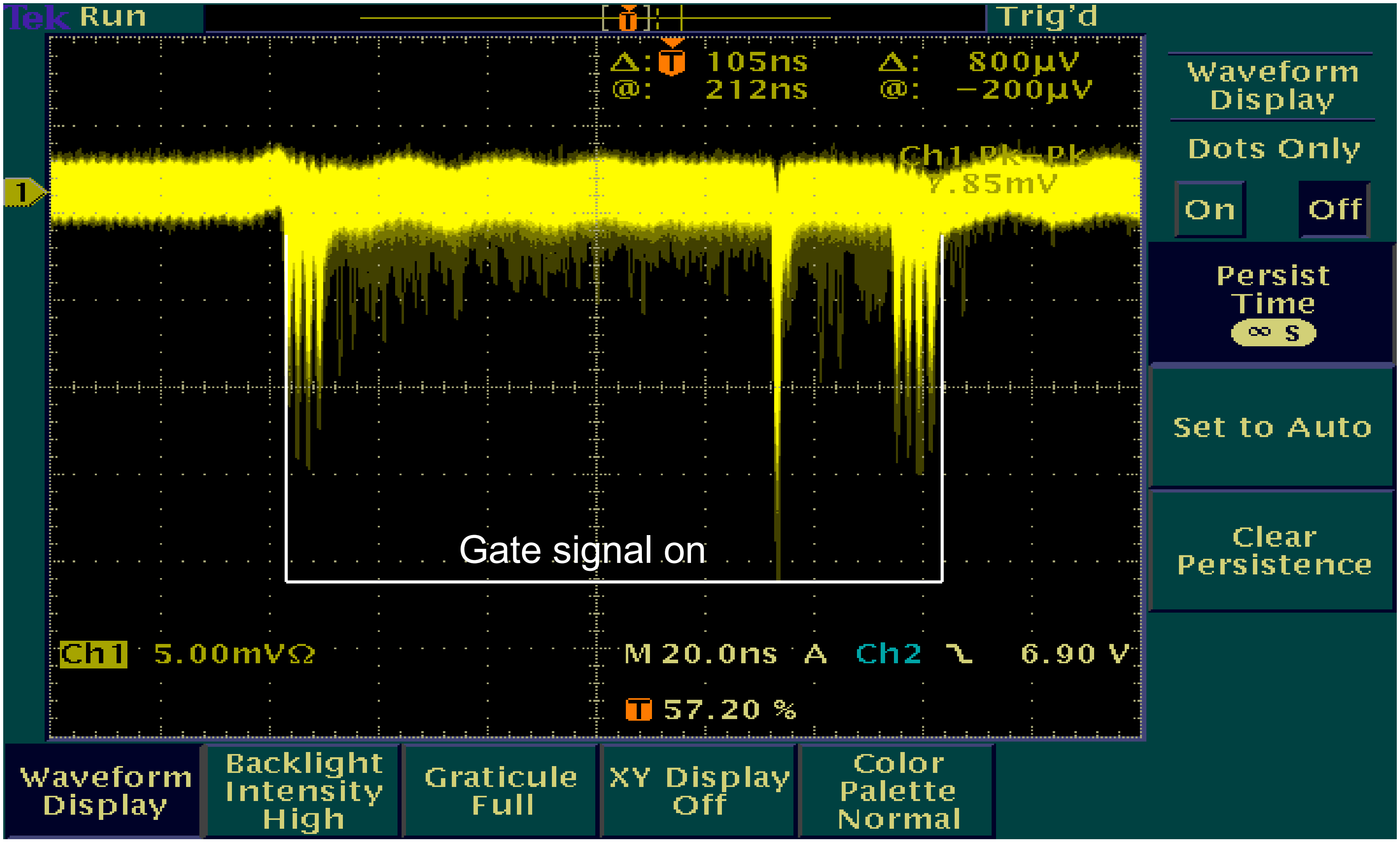


(LHC parameters)

Experimental setup

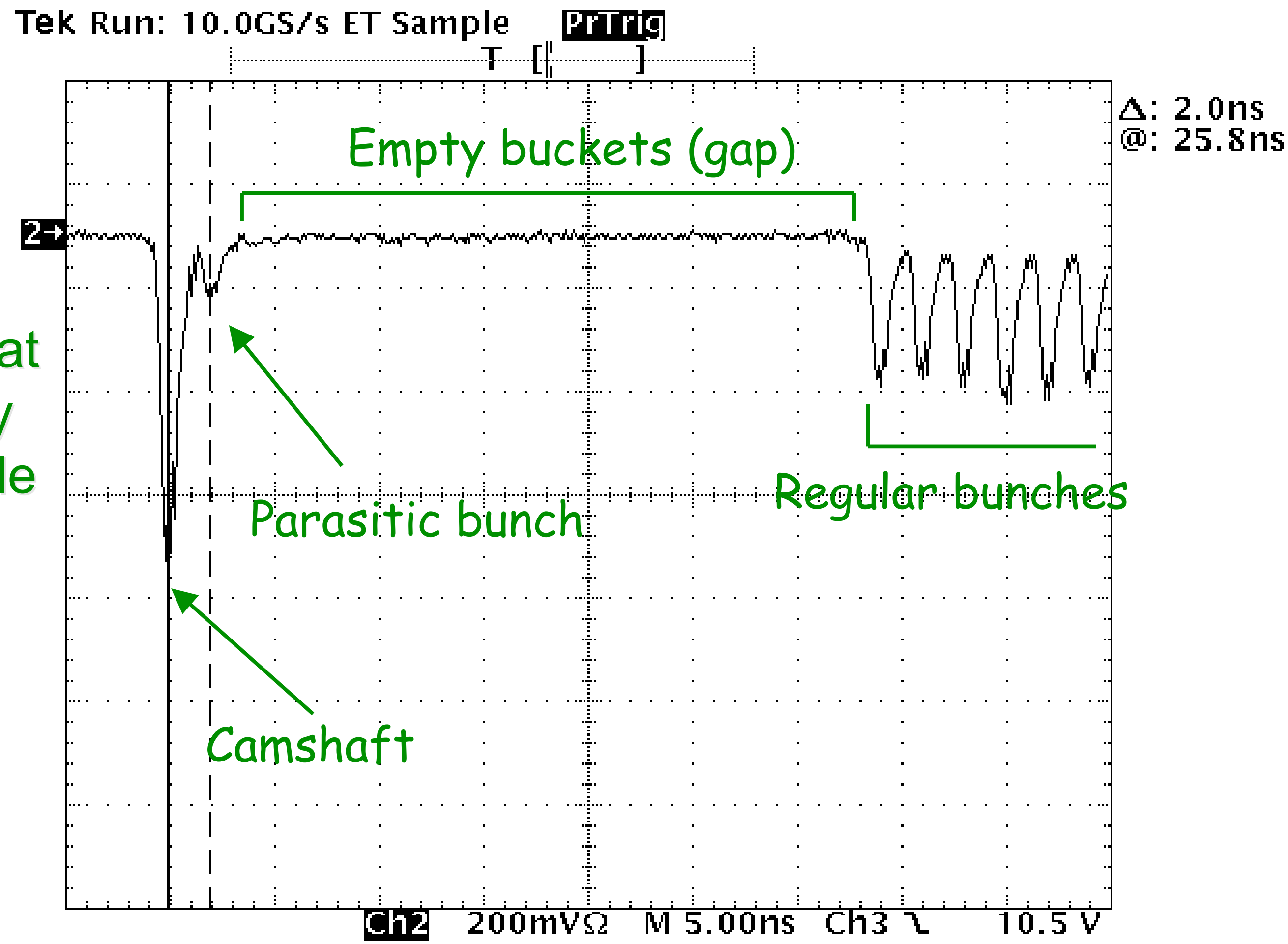


First experimental data



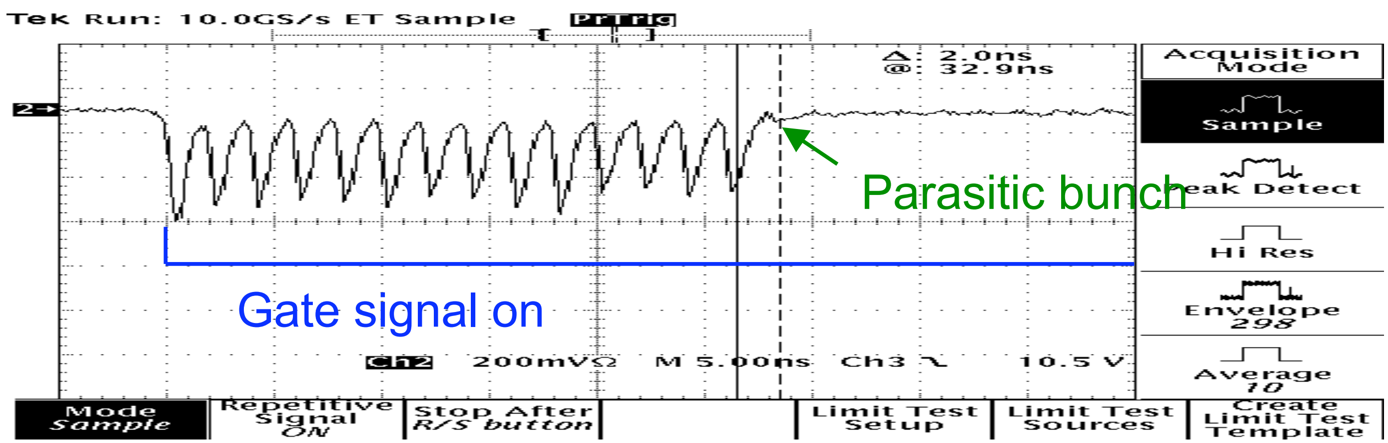
…and more recent data

No need to average data, at least at the ALS.
Future experiments at the ALS will carefully evaluate the available photon flux and simulate the LHC parameters, if possible.

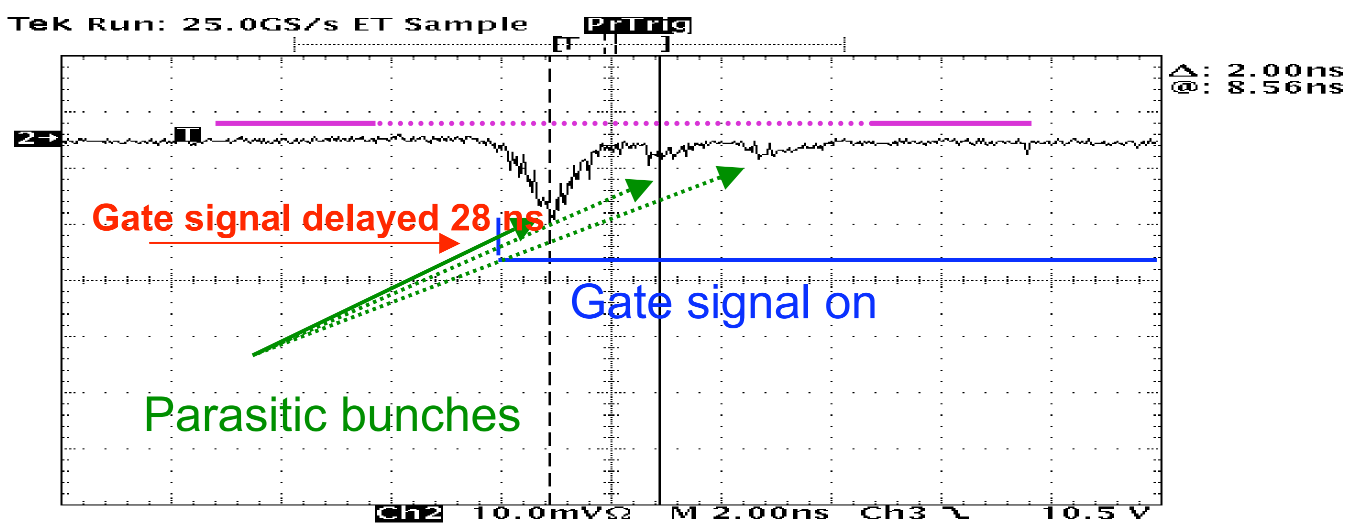


Some more interesting data

Photocatode recovery is not an issue

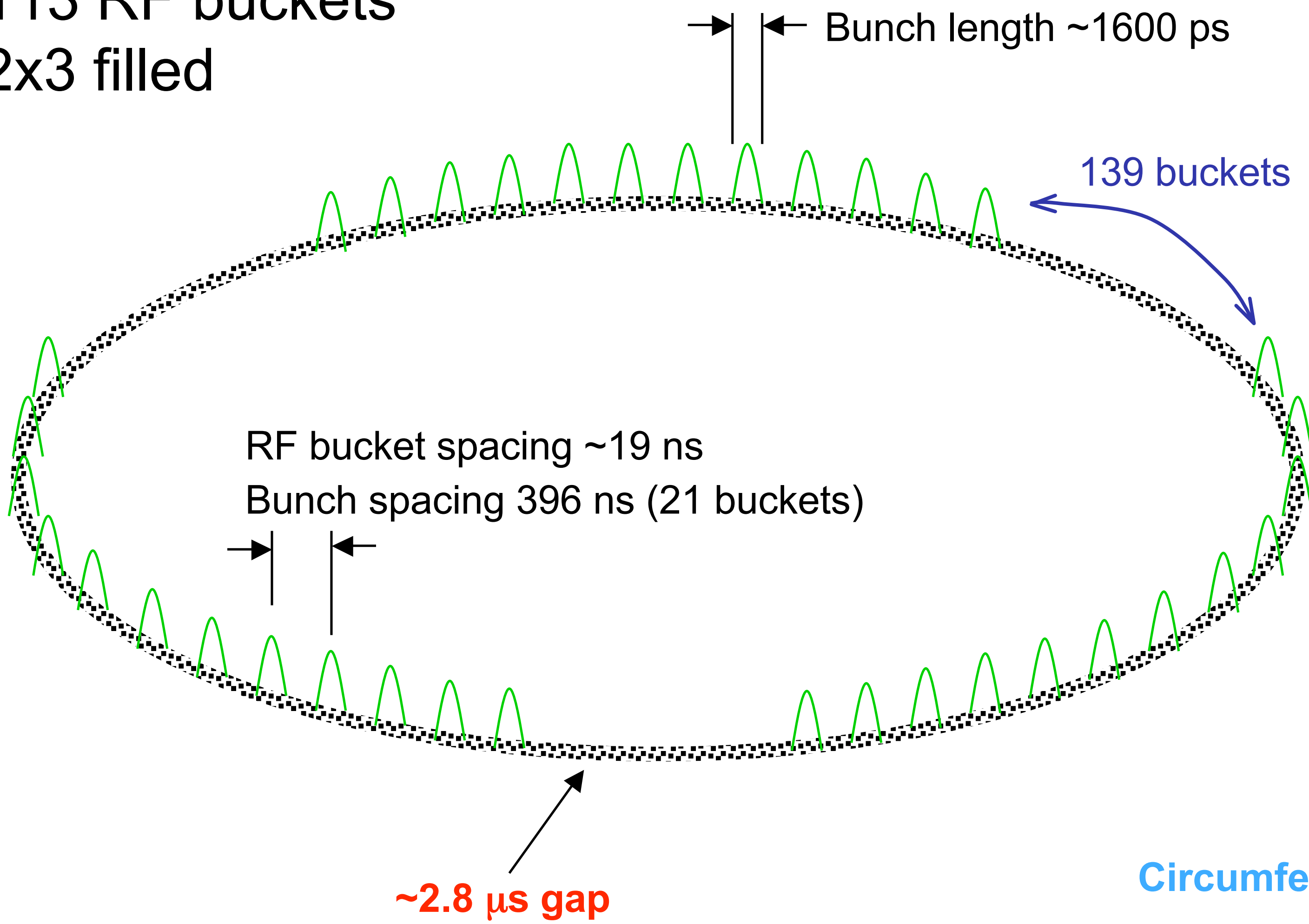


Compare zero level with gate on and off



Tests at the Tevatron

1113 RF buckets
12x3 filled

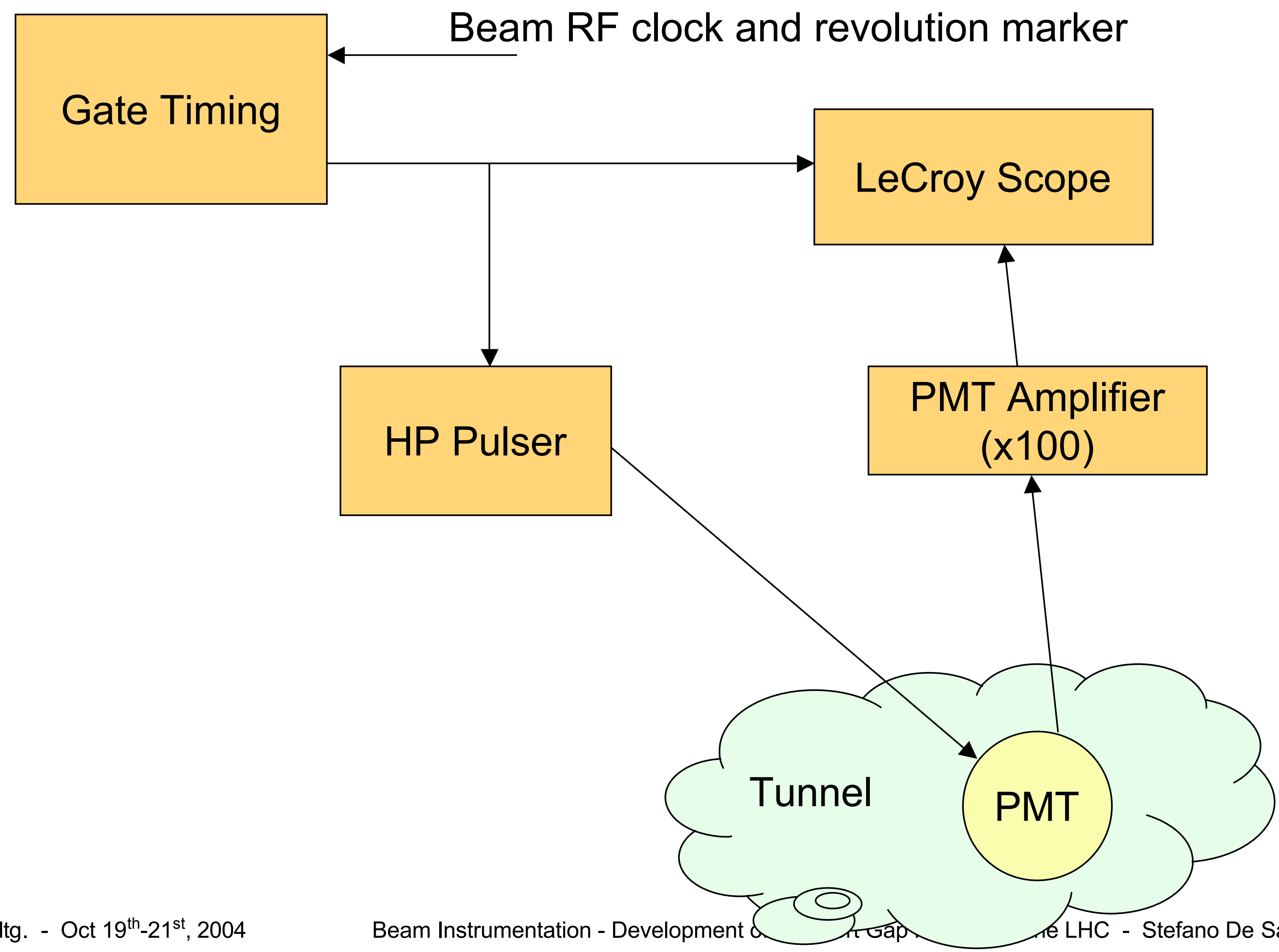


Circumference: 21 μs

Tests on the Tevatron

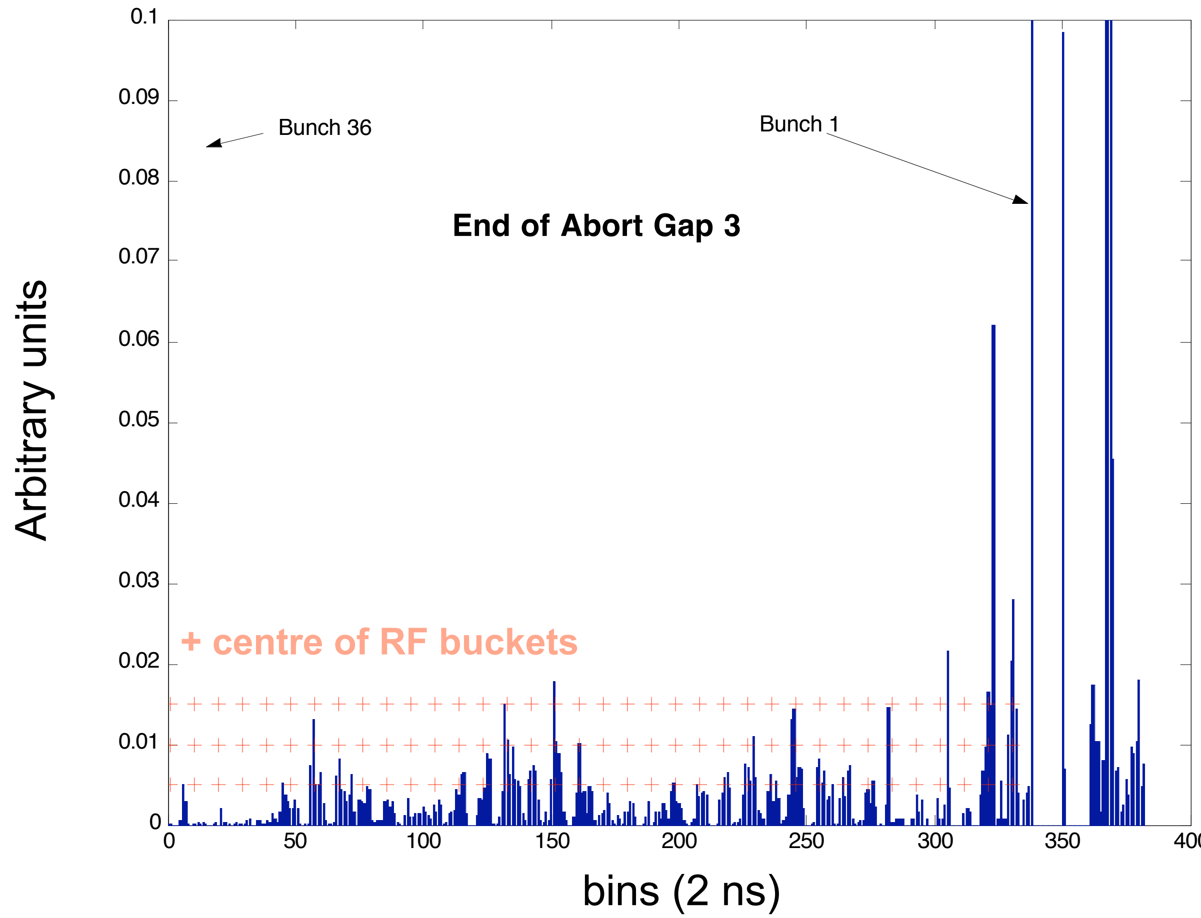
- PMT is gated on for a period where we want to count photons
- LeCroy scope tallies times of arrival of individual photons
- Tevatron Electron Lens (TEL) produces gap in longitudinal distribution
- Microbunches are visible in end of abort gap
  - Level of microbunches is ~10^7 particles / rf bucket
- No structure visible in front half of abort gap
  - Pbars are injected in front half, so kicker cleans that part

PMT Photon Counting Setup



Single photon counting at the Tevatron

Bunch 36 is 2 μs to the left of this plot



- 1 μs gate
- average of 3 gaps
- counts accumulated over 1000 turns

Microbunches are clearly visible

Timing of the AGM

One 100 ns long sample every turn (1% duty cycle)

- 33 samples to map entire abort gap.
- Abort gap mapped 33 times in the 100 ms integration time.
- “Interleaving” samples necessary for detecting charges falling across two samples.

Alternatively, use 825 ns long samples (max window allowing 1 sample per turn).

- Entire gap is now mapped in 4 turns.
- 275 averages in 100 ms
- This maximizes S/N, but needs more complex data acquisition (multiple integrators)

AGM Summary

MCP-PMT is a viable technique

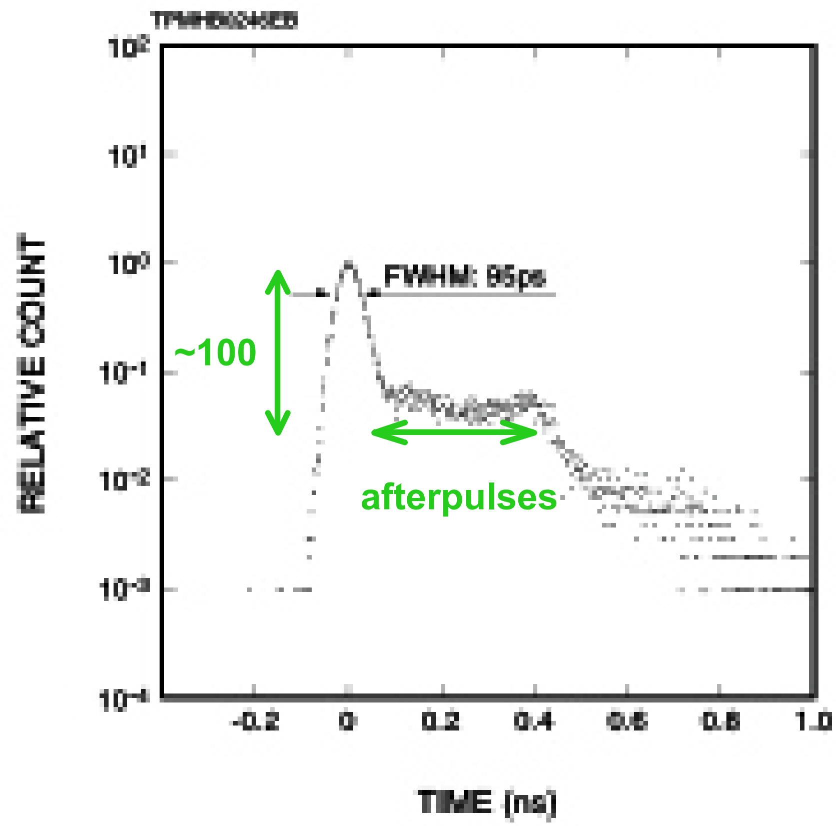
- Can be easily switched at the required speed
- S/N ratio seems more than adequate
- Fast photocatode recovery (~100's ps)
- Tested at the ALS and the Tevatron
- Can monitor the accumulation of charges in the gap, rather than just detecting when threshold level is reached
- Can also be used to monitor the unbunched beam around the ring
- Can monitor bunch tails and ghost bunches at a reduced resolution
- Specifications for data acquisition hardware

Fundamental limit to resolution

Why not use a MCP-PMT for accelerator physics studies too ?

Impulse Response Function for gateable PMT's is on the order of 100 ps. The MCP-PMT could be conceivably used for AP measurements.

The 50 ps time resolution required, could be perhaps achieved by inverse filtering



Diagnostics for measuring longitudinal parameters of the LHC beams

- **Abort Gap Monitor**

- **Debunched Beam**
- **Bunch Tails**
- **Ghost Bunches**

- **Bunch Core ("real time")**

MODE		SENSITIVITY: Ultra-high	SENSITIVITY: High	SENSITIVITY: Standard
Observation period (ns)		100	0.05	0.05
Integration time (s / rev)		0.1 / 1100	$10 / 10^5$	$10^{-3} / 10$
UPD (p/ps)	0.45TeV		$0.9\text{x}10^8$	
	7TeV		$2\text{x}10^8$	
Sensitivity (p/ps)	0.45TeV	$\leq 4\text{x}10^4$	10^4	10^6
	7TeV	≤ 60		
Sensitivity/UPD	0.45TeV	$4.4\text{x}10^{-4}$	$5\text{x}10^{-5}$	$5\text{x}10^{-3}$
	7TeV	$3\text{x}10^{-7}$		
Dynamic range (p/ps)	0.45TeV	$4\text{x}10^5$	$10^4 - 3\text{x}10^8$	$10^6 - 5\text{x}10^8$
	7TeV	$6\text{x}10^4$		
Accuracy (p/ps)	0.45TeV	$\leq \pm 2\text{x}10^3$	$\pm 4\text{x}10^3$	$\pm 10^4$
	7TeV	$\leq \pm 30$		
Transmission rate (s)		≤ 1	60	0.1

APPLICATIONS	Ultra-high	High	Standard
Abort Gap monitoring	X		
Tails		X	
Ghost bunches		X	
De-bunched beam		X	
Calibration		X	
Core parameters			X

Radiation Flashes

- Caused by untrapped particles lost on the aperture during ramp.

- The momentum cleaning system (collimators in IP7) takes care of most of it. Additionally, beam loss is not so concentrated as in a beam dump.

- Maximum allowable charge density between bunches: $2 \cdot 10^5$ p/ps. Much higher than in the abort gap, but needs monitoring all around the ring.

An MCP-PMT based instrument can map entire ring in 100 turns